BEAR CREEK

HYDROLOGIC INVESTIGATION

Incorporating both water quantity
and quality considerations in urbanizing watersheds.

by

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EXECUTIVE SUMMARY

Hydrologic modeling is useful for local communities to evaluate the effects of planned zoning on streamflow within a watershed. Urbanization, if left unchecked, can cause detrimental impacts to a watercourse. These impacts include increased peak flows, reduced baseflow, channel erosion, elimination of pools and riffles, less diverse fish and aquatic communities, increased water temperatures, increased soil erosion and increased pollutant loads to the watercourse. Some of these impacts are due to the increased volume of runoff which results from urbanization and its associated paving and land use changes. Other impacts are due to the increased pollutants and sediments which wash off impervious areas and construction sites.

A hydrologic model was developed which divided the Bear Creek Watershed into 37 subwatersheds. Based on land use and soil information from each subwatershed, the model develops flows from each area. These flows can be combined at various locations to represent a composite runoff hydrograph. With this model, the land use for a subwatershed can be changed and the potential impact on downstream flows can be evaluated. The model can also be used to evaluate regional retention sites.

The model was used to evaluate what affect potential urbanization would have on peak streamflows in Bear Creek. Three scenarios were evaluated:

1) Existing land use conditions using 1978 land use information;

2) Future land use assuming ¼ acre residential development throughout the watershed;

3) Future land use assuming 75% ¼ acre residential development, 25% open space.

The scenarios were modeled assuming no retention/detention requirements. The 2-year, 25-year and 100-year 24 hour rainfall events were used with the model. Model results down to Waddell Creek (da = 29 square miles) are summarized below:

	1978 Conditions		¼ Acre Development		75% ¼ Acre 25% Open Space	
	2-yr.	100-yr.	2-yr.	100-yr.	2-yr.	100-yr.
Bear Creek u/s of Waddell Creek, DA = 29 mi^2	360 cfs	1750	560	2300	420	1950

If no retention/detention requirements were imposed with the full ¼ acre development, the above comparison indicates that there would be a 30% increase in peak flows produced by the 100-year rainfall and a 60% increase in flows produced by the 2-year rainfall. This increase in flow would cause additional flooding and channel scouring which would affect the quality of the creek. Some of the individual subwatersheds which were meadow had flow increases of 2-3 times. The reason for this is that with sandy soils in a meadow condition most of the 2-year rainfall infiltrates into the soil. The majority of the soils in the Bear Creek watershed are sandy or sandy loams which means that adding impervious surface will cause a much higher percentage of runoff.

The 75% ¼ acre, 25% open space scenario results in a 10% increase in peak flows produced by the 100 year rainfall and a 17% increase in flows produced by 2 year rainfall. Even though these increases are less than the full development scenario, they may still be large enough to cause channel erosion. A stream tends to reach a stable condition based on a given flow regime. Once those flows are altered due to development, the stream will become larger to handle the increased flows. In this low density development scenario, the on-site and upland erosion control practices are important in keeping additional sediment out of Bear Creek. There is currently a lot of sediment build up in the vicinity of Egypt Valley Road. Its source is unknown. Maintaining a greenbelt along the stream would also help to keep additional sediment out of the stream, as well as help preserve habitat values and water temperatures.

Commercial or industrial development would cause a higher increase in flows because of the greater amount of imperviousness. In those areas a greater amount of retention/detention would be needed.

Some states and communities across the country have retention/detention requirements to meet both water quantity and quality concerns. Many Michigan communities have regulations dealing with increased water quantity caused by urbanization, but very few have addressed retention/detention requirements to deal with water quality issues. In order to address both concerns, a comprehensive approach is needed. Water quantity concerns are usually dealt with by requiring that retention/detention be used to limit peak runoff rates after urbanization to what they were before development or less. This requirement is usually applied to the entire community even though detention at the downstream end of the watershed could actually increase flows due to delaying of the peak (Figures 6a, b, c). Modeling can be used to address this potential problem, at least on a regional scale.

In order to address water quality concerns, several things can be done which are often called Best Management Practices (BMP's). Some of these are listed below.

1) Provide a buffer or greenbelt along all streams, drains, wetlands and lakes. Requirements for buffer widths vary from 25 to 200 feet (on small streams, water temperatures may increase 1.5° F per 100 feet when flowing through unshaded reaches).

2) Maintain as much vegetation and green area as possible. (Stream temperatures may increase .14° F per 1% imperviousness).

3) Use grassed swales instead of curb and gutter.

4) Disconnect downspouts from sewers.

5) Use sediment sumps in storm sewers.

6) Provide shade for retention/detention ponds and their inlets and outlets.

7) Restrict development in environmentally sensitive areas.

8) Possible use of cluster development which minimizes the disturbed area.

9) Use strict soil erosion controls at construction sites.

10) Avoid clear cutting a development site all at once. Do the construction in a staged manner, stabilize one area before moving on.

11) Use a sediment basin at construction sites. A recent Maryland study suggested that a basin volume sized at 3600 ft^3/acre be used.

12) Provide retention/detention for small rainfall events up to the 2-year storm.

Item number 12 deals with retention/detention requirements to address water quality concerns. Small runoff events pick up and deliver the majority of the pollutants to a watercourse. Nationally, the amount of runoff to be treated varies from .5 inches per impervious acre up to the amount of runoff provided by a 2-year 24 hour storm. The runoff volume can be treated in two ways:

1) The runoff is directed to an infiltration basin or trench with no outlet. The water infiltrates into the ground within 72 hours. In order for this method to be used, the infiltration rate of the underlying soils should be .52 inches/hour. Most of the soils in the Bear Creek Basin are sands and sandy loams which should meet this requirement. The bottom of the basins should be 4 feet above the seasonally high ground water table. Infiltration provides for the highest removal of pollutants in the runoff and causes the least impact on increasing stream temperatures.

2) The runoff is directed to an extended detention or wet retention pond. The volume of runoff should be filtered out over a 24-48 hour period to allow for settling of some of the pollutants.

Typical dry detention basins with an open pipe at the bottom which allows everything to flow out does very little for water quality. Infiltration basins and retention/detention ponds can be designed to handle both water quality and water quantity concerns.

If Bear Creek is a unique and valuable resource in this area, then the local governmental agencies in the watershed need to develop policies and guidelines to protect it.

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Introduction

This report evaluates the existing hydrology for the Bear Creek watershed and analyzes the effects on flood flows due to the increased urbanization which has and will take place. It is the intent of the report to show how modeling can be used to document these effects and how modeling can be used as part of the community planning process. Local officials will be provided the Bear Creek watershed model to aid their decision making process regarding land use changes.

Unregulated development can lead to increased flows and have damaging impacts on the water quality of a stream system. Urbanization tends to fill in areas which provide storage, and pave over other areas which prevent infiltration. These actions produce higher runoff volumes with greater flood peaks that occur more quickly. Schueler (1987/90) indicates that increased urbanization has the following impacts on a stream system:

- Peak discharges are increased 2-5 times over predevelopment peaks.
- The frequency of bankfull flooding events may increase from once every two years to 3-5 times each year. A stream that over the years has naturally adapted to handle bankfull flooding will now be reshaped due to increased quantities (50% more runoff) and velocity of water. There will be channel down cutting and widening (2-4 times wider), streambank erosion, falling trees and slumping banks.
- Runoff will reach the stream much faster (up to 50%).
- Reduced baseflow because less infiltration is taking place.
- Pools and riffles are eliminated due to sedimentation and changes in channel characteristics. This has a direct affect on the aquatic community and the number and types of organisms found there.
- Fish communities become less diverse with a sharp decrease or elimination of sensitive fish species.
- The amounts of pollutants entering the stream system during and after development increase by an order of magnitude.
- The temperature of an urban stream may increase linearly .14 degrees Fahrenheit per 1% increase in imperviousness (Galli, 1990).

Some Best Management Practices (BMP's) will be discussed which help control some of the above impacts. A publication entitled "Stormwater Management Guidebook", MDNR 1991, provides more detailed design considerations for BMP's related to stormwater detention/retention.

This report is designed to encourage local officials, planners and engineers to evaluate water quality issues related to urbanization. Many communities in Michigan have started to address water quantity concerns, however, very few have taken the next step to address water quality. Some states have adopted laws to address this concern, but Michigan currently has none.

Background

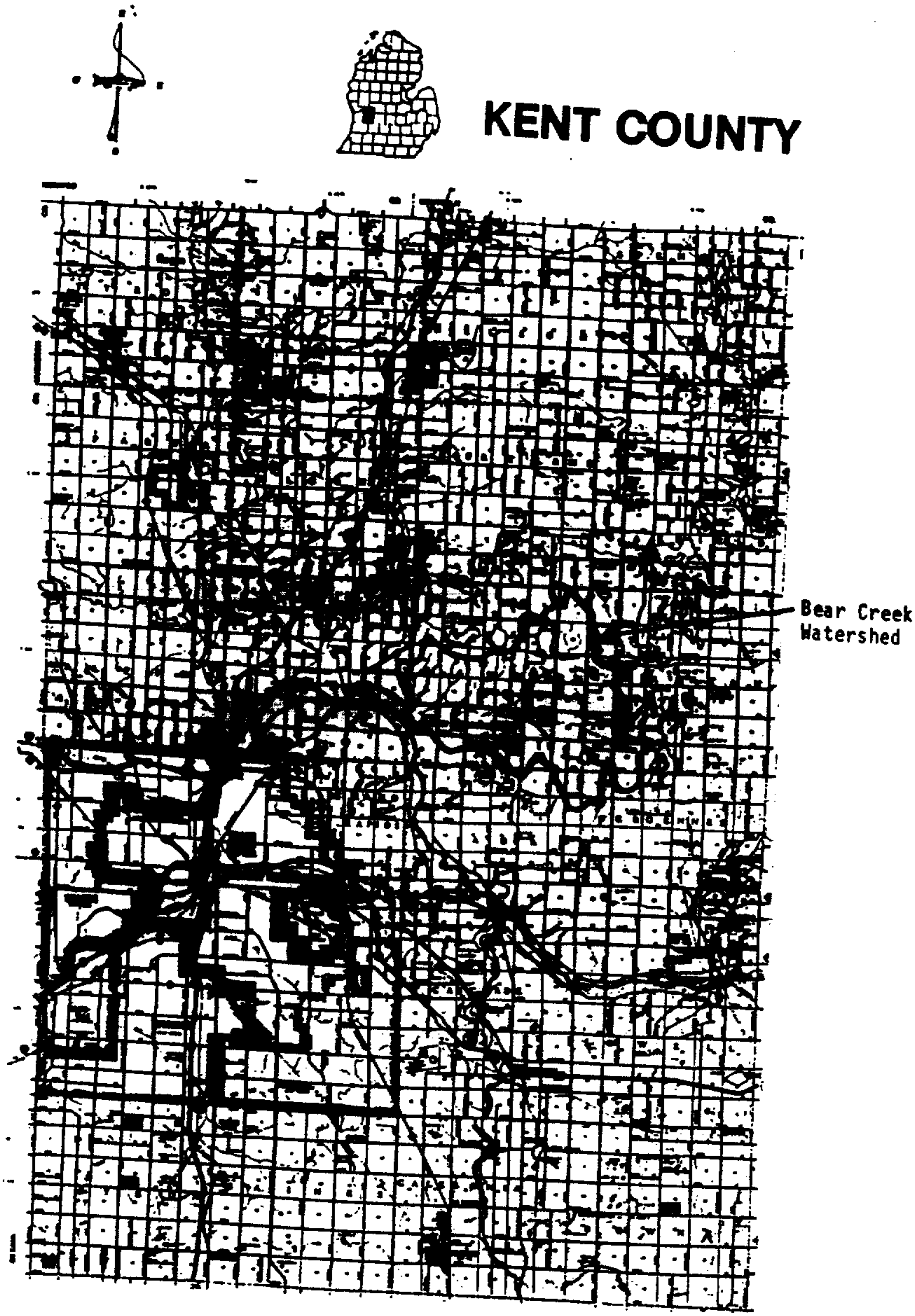
The Bear Creek Watershed is located in Kent County near Grand Rapids, Michigan (Figure 1). The majority of the watershed is in Cannon Township. Small portions of the watershed are also within the Townships of Grattan, Vergennes, Ada and Plainfield. The headwaters of Bear Creek start near Bostwick Lake. From there, the creek flows south approximately 2 miles, before turning west through Cannonsburg toward the Grand River (Figure 2). There are several small tributaries which drain into Bear Creek along its main course. The eastern end of the watershed contains several wetland areas and a few lakes, the largest of which is Bostwick Lake with a surface area of about 210 acres. The average slope of Bear Creek is .35% (18.6 ft/mile). The tributaries in the eastern portion of the watershed have slopes similar to this or flatter. The tributaries in the western end are much steeper with slopes up to 2.8% (150 ft/mile).

Modeling

In order to evaluate the affects of land use changes on flows in Bear Creek, a HEC-1 model was set up. HEC-1 is a computer model developed by the U.S. Army Corps of Engineers which simulates runoff for a given design storm. The model, which can be run on a personal computer, is able to develop runoff from several subbasins and combine them to develop a composite hydrograph at various locations. One can change the land use for a subwatershed and determine the affects on flows at some downstream point in the watershed.

The Bear Creek watershed was divided into 37 subwatersheds (Figure 3) ranging in size from .06 square miles (38 acres) to 2.78 square miles (1780 acres). The downstream end point for this model is just upstream of Waddell Creek which is approximately 300 feet upstream of the Grand River. The contributing drainage area is 29.0 square miles. Land found to be noncontributing (in terms of storm runoff) either through map inspection or visual inspection, was not included in the model. Noncontributing area is usually isolated from the watershed because there are no or very restrictive road culverts or it is an area which drains to a large

FIGURE 1



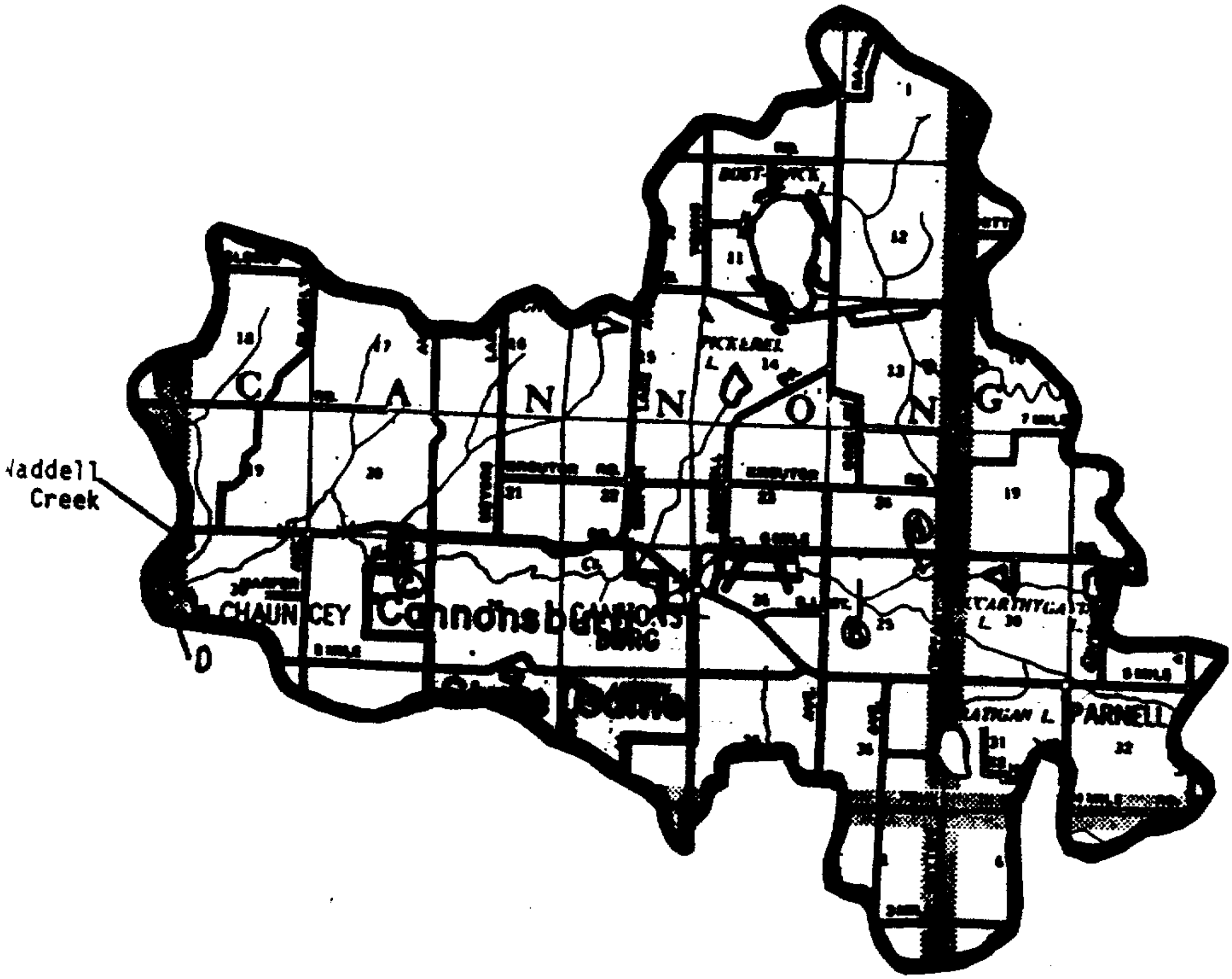


FIGURE 2

BEAR CREEK WATERSHED

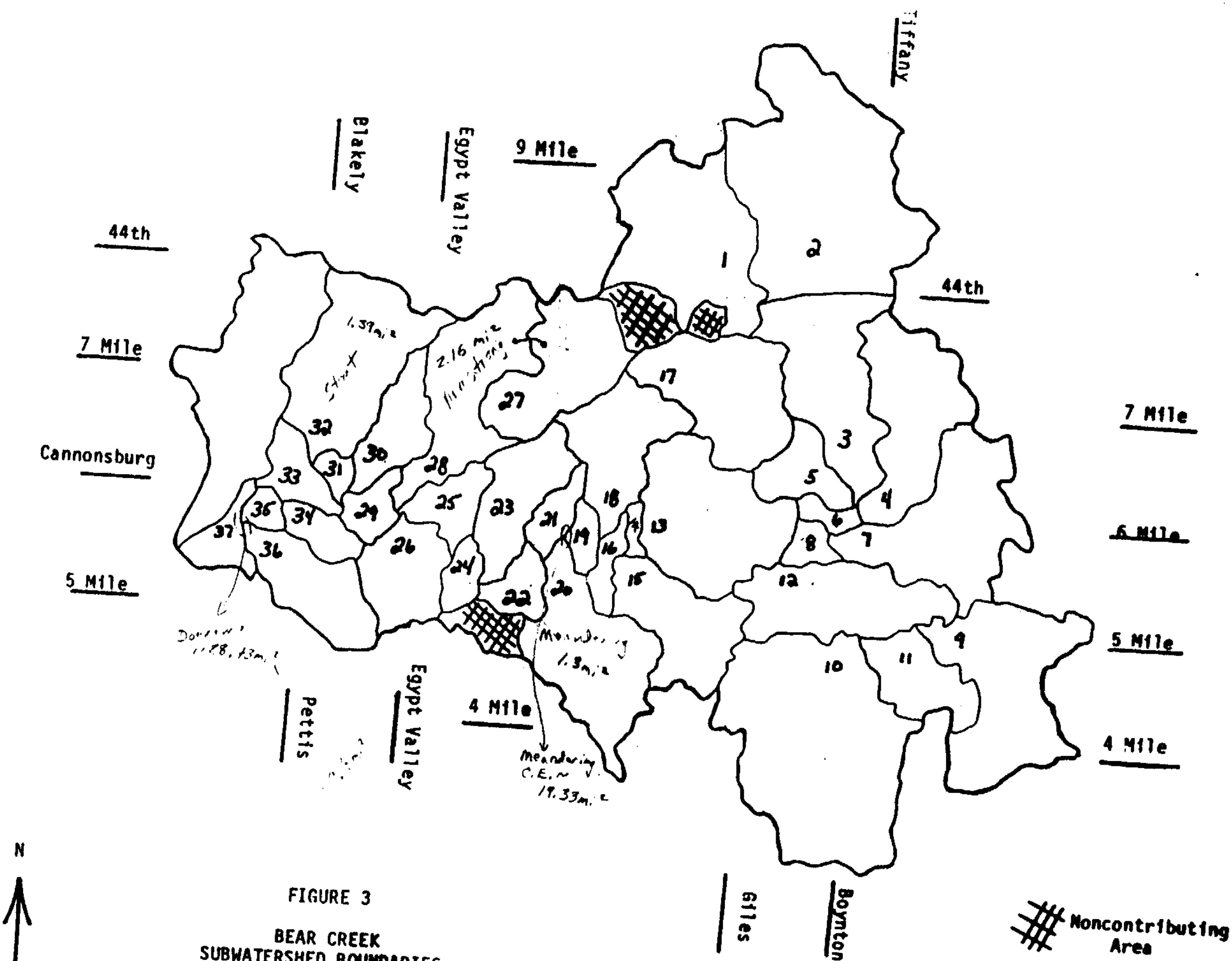


FIGURE 3

BEAR CREEK
SUBWATERSHED BOUNDARIES

pothole with no outlet. The amount of noncontributing area is estimated to be .6 square miles. These are shown as shaded areas in Figure 3.

Inputs into the HEC-1 model for each subbasin include a curve number, which relates runoff to soils and land use for a particular rainfall, and lag (.6 x time of concentration). Other required information for the model are reach lengths and slopes from one subbasin to the next and stage-storage-discharge relationships for any culverts or structures which may attenuate (lower) flood peaks.

Soils

The soils in this area are primarily sand, loamy sand, sandy loam and loam with some muck soils in the low lying areas. The Soil Conservation Service groups all soils into four main categories A, B, C and D related to their runoff potential. The Type A soils have a low runoff potential and high infiltration rates, while the D soils have a high runoff potential and very low infiltration rates. The following table indicates the texture class, the minimum infiltration rate and the hydrologic soil grouping for various soils (Rawls, 1982):

TABLE 1

Texture Class vs Infiltration vs Soil Grouping

Texture Class	Minimum Infiltration Rate inches per hour	Soil Grouping
Sand	8.27	A
Loamy Sand	2.41	A
Sandy Loam	1.02	B
Loam	.52	B
Silt Loam	.27	C
Sandy Clay Loam	.17	C
Clay Loam	.09	D
Silty Clay Loam	.06	D
Sandy Clay	.05	D
Silty Clay	.04	D
Clay	.02	D

The percentage breakdown for the soils in the Bear Creek Watershed are:

A	43%
B	37%
C	3%
D	17%
	100%

Because of the high percentage of A and B soils in the Bear Creek watershed, the runoff potential is very low when left undeveloped. Urbanization with its associated paving and storm sewers will greatly increase the runoff potential from these soil types. As noted on Table 1, the infiltration rates of the A and B soils is very high. These high rates of infiltration are beneficial when designing retention/detention systems to reduce the affects of urbanization. Infiltration basins are recommended when treating runoff from developed sites. In order to be effective, this type of BMP must have underlying soils which have infiltration rates of .52 inches or more. The majority of the soils in this watershed appear to meet this criteria.

Land Use

Land use information was derived from the Michigan Resource Information System (MIRIS). These data are based on interpretation of 1978 aerial photographs. This was then used as the basis of establishing existing conditions prior to significant development. Table 13 (Appendix A) lists the land uses which are contained in the MIRIS data base. For this study several of the uses were grouped together and treated similarly as far as runoff potential. For example, all of the land uses listed under forest (411-429) were grouped together. Table 2 lists the 1978 land use in the Bear Creek Watershed down to Waddell Creek.

TABLE 2

1978 land use data

Forested	
Herbaceous	35%
Crop	4%
Shrub	37%
Pasture	14%
Urban-Residential	2%
All Other	4%
	4%
	100%

Cannon Township is currently creating a Master Zoning Plan which will establish goals for future land use development. For this report, two future development scenarios were looked at. One assumed ½ acre residential development throughout the watershed, and the other assumed 75% would develop as ½ acre residential and 25% would remain as open space.

Curve Number

The curve number is a term which relates the runoff potential for a given rainfall to the soils and land use for a given site. Table 3 lists some of the curve numbers which were used in this report. To convert the curve number to a runoff value for a given rainfall, figure 4 can be used. The following equations can also be used:

$S = (1000/CN)-10$, CN = curve number
Runoff (SRO) $= (P-.2S)^2/(P+.8S)$, P = design rainfall

TABLE 3

Land Use vs Soil Type vs Curve Number

MIRIS Land Use Code	MIRIS Land Use Type	Curve Number vs Soil Type A	B	C	D
111,112	Multi-Family	77	85	90	92
113	Single Family (¼ acre)	61	75	83	87
115	Mobile Home Park	77	85	90	92
121,122	Commercial	89	92	94	95
138	Industrial	81	88	91	93
21	Cropland	65	77	84	88
22	Orchards	43	65	76	82
23	Confined Feeding	68	79	86	89
24	Pasture	49	69	79	84
32	Shrub	30	58	71	78
31	Herbaceous	49	69	79	84
411-429	Forest	45	60	73	79
51-54	Water	100	100	100	100
193,194	Open Land	39	61	74	80
611	Wooded Wetland	45	60	73	79
612	Shrub, Scrub Wetland	30	58	71	78
621,622	Aquatic, Emergent Wetland	100	100	100	100

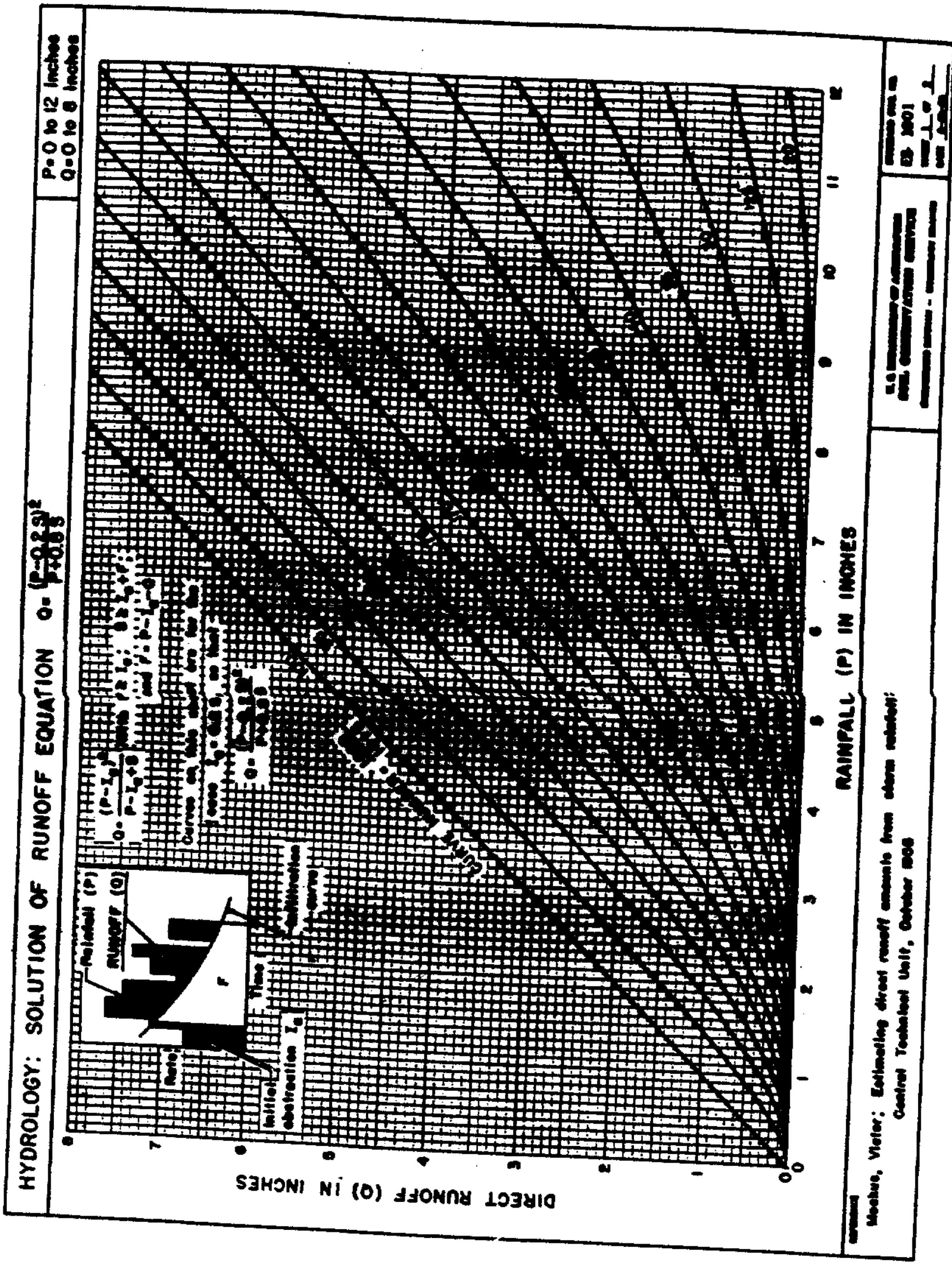


FIGURE 4

HYDROLOGY: SOLUTION OF RUNOFF EQUATION

Example:

Determine the runoff for a rainfall of 4.45 inches, B soils and ¼ acre residential lot.

From Table 3 CN = 75 for ¼ acre lot on a B soil

$S = (1000/75)-10 = 3.33$
$SRO = (4.45 - .2(3.33))^2/(4.45+8(3.33) = 2.01$ inches

The runoff amount would be 2.01 inches.

The following example shows how to compute the runoff from a .8 square mile (512 acre) area, and how to determine an average curve number for that area. The rainfall amount is 4.45 inches.

Soils Group	%	Mi²	Land Use	%	Mi²	CN	S.R.O.	Sq. Mi-In
A	30	.24	Forest	20	.05	45	.28	.01
			Crop	30	.07	65	1.30	.09
			Commercial	30	.07	89	3.25	.23
			Herbaceous	20	.05	49	.44	.02
B	70	.56	Forest	10	.06	60	1.00	.06
			Crop	25	.14	77	2.17	.30
			Urban (¼ Acre)	50	.28	75	2.00	.56
			Herbaceous	15	.08	69	1.56	.13
								1.41 sq. mi-in

The total volume of runoff for this .8 square mile area is 1.41 sq. mi-in = 75 acre-feet.

The average amount of runoff over this area is 1.41 sq. mi-in/.8 sq. mi = 1.77 inches.

The average curve number for 1.77 inches of runoff from a rainfall of 4.45 inches is 72 (from Figure 4).

Time of Concentration

The time of concentration is defined as the time it takes for rainfall to travel from the hydraulically most distant part of the watershed to the outlet of the subbasin. For this report the time of concentration (Tc) was determined as follows:

$$Tc = \text{Length (feet)}/(V \times 3600)$$

V is a velocity term (ft/sec) which is defined by the equation, $V = KS^{.5}$, where S = slope in percent for a particular segment and K varies according to the following flow regimes:

$V = 2.1S^{.5}$ (for small tributaries, and swamps with channels)
$V = 1.2S^{.5}$ (waterways, flow through swamps without channels and valleys well defined by contours)
$V = .48S^{.5}$ (sheet flow)

The following is an example on how Tc can be computed for a subwatershed.

Type	Length (ft)	Elev.	Slope %	K	$V=KS^{.5}$	Tc = Length/3600V
sm trib	2520	728-692	1.43	2.1	2.51	.28
sm trib	4800	826-728	2.04	2.1	3.00	.44
waterway	3010	934-826	3.59	1.2	2.27	.37
waterway	1660	954-934	1.20	1.2	1.31	.35
						1.44 hrs.

The Tc for this subwatershed is 1.44 hours.

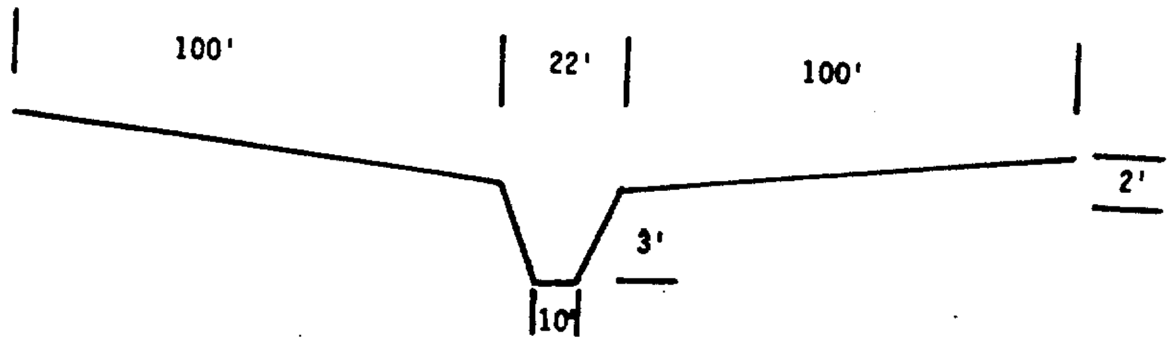
The number of segments used to determine the total Tc within each subwatershed is dependent on the slope. Segment lengths should be picked which have uniform slopes. In looking at future conditions, it is expected that the Tc would be shortened due to development as a result of paving, curb and gutters and storm sewers. For this report, the Tc for future conditions was shortened by assuming that all of the segments were small tributary where K = 2.1. With the above example, the future Tc would be 1.13 hours. Shorter Tc's result in higher flood peaks.

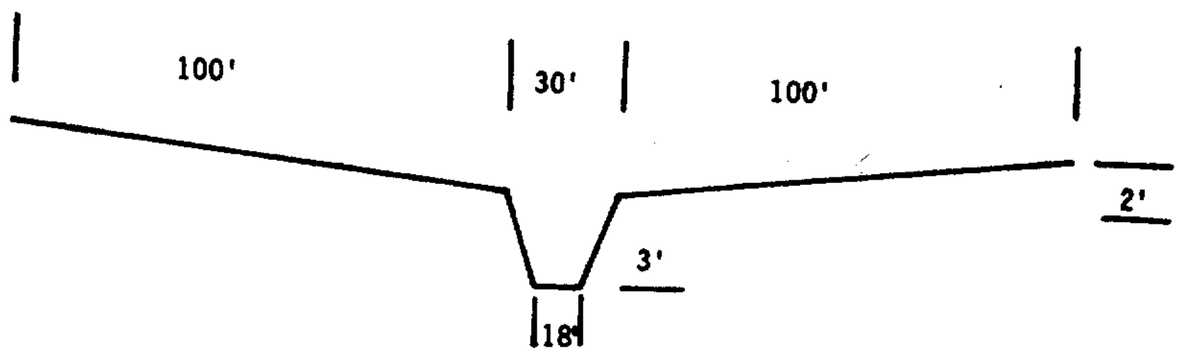
Stage-Storage-Discharge

For the purposes of this model, outflow from Bostwick, Ratigan and Pickeral Lakes was limited to 1-2 cfs for all conditions. It was assumed that most of the runoff draining to the lakes would be stored in the lakes with very little outflow. In order to better approximate lake outflows, a more detailed stage, storage, outflow relationship would be needed for each of the lakes. No routing was done through any of the road crossings because they appeared large enough or had small amounts of road fill which would prevent much attenuation.

Cross-Section, Reach Lengths

Reach lengths from one subbasin to the next were measured off the USGS quadrangle. A uniform cross-section shape was estimated from field observation and is shown below. This was used for the upper areas.





cross-section used in lower reaches

Modeled Scenarios

To evaluate the effect on flows due to future development, three scenarios were simulated.

1) Existing conditions based on 1978 land use information

2) Developed conditions - Assuming ¼ acre residential development throughout the watershed.

3) Developed conditions - Assuming 75% ¼ acre residential development and 25% open space.

Once Cannon Township finalizes their Master Zoning Plan, those land uses could be input into the model and evaluated.

The 24 hour duration rainfall frequencies for this area are listed in Table 4 below. These were taken from Technical Paper 40 (TP40, Reference 13).

Table 4
Rainfall Frequencies

1 year 24 hour =	2.2 inches
2 year 24 hour =	2.45 inches
5 year 24 hour =	3.15 inches
10 year 24 hour =	3.65 inches
25 year 24 hour =	4.15 inches
50 year 24 hour =	4.55 inches
100 year 24 hour =	4.9 inches

For this model, a Type 1 rainfall distribution (Appendix B) was used with the 2 year, 25 year and 100 year rainfall frequencies.

Table 5 lists the subbasins and drainage areas along with the curve numbers and times of concentration for each of the 3 scenarios. Although the noncontributing area was not included in the future scenarios, an argument could be made that these areas would be connected or drained and would contribute additional runoff to the watershed.

Table 6 lists flows at four locations in the watershed for the 2-year, 25-year and 100-year frequency storms for each of the three scenarios.

As shown in Table 6, increased development without any retention or detention requirements will increase flows throughout the watershed. The full ½ acre residential development will cause a 60% increase in peak flows for the 2-year rainfall event and a 30% increase in peak flows for the 100-year rainfall event. The percentage increase would be higher if there were commercial and industrial development. For example, when looking at Subbasin 9 the curve number is 74 for existing conditions and 76 with full ½ acre residential development. If the subbasin were to develop commercially, then the curve number would be 92. A comparison of flows for these three conditions is listed below.

Subbasin 9 DA = 1.54 mi2	Existing CN = 74	½ Acre CN = 76	Commercial CN = 92
	2 yr. = 50 cfs	2 yr. = 65	2 yr. = 200
	100 yr. = 250 cfs	100 yr. = 280	100 yr. = 500

The commercial land use represents a condition which is 85% impervious. As a result of this high degree of imperviousness, there is substantially more runoff which in turn will produce higher flows.

Table 7 lists the 2-year, 25-year and 100-year flows for each subwatershed for the three modeled scenarios. Some of the individual subbasins have a 2-3 fold increase in flows for proposed versus existing conditions with the 2-year rainfall.

Note

When using a 2-year 24-hour rainfall with the curve number procedure, very little runoff is produced when the curve number is low. This methodology is okay if it is being used as a design criteria. However, the actual 2-year flow may be higher than this computed value because the 2-year flow is often dependent on springtime snowmelt conditions and not necessarily a rainfall event. A drainage area ratio to a gaged stream of similar hydrologic characteristics may be a more appropriate way of estimating an actual 2-year flow.

TABLE 5

Comparison of Curve Numbers and Times of Concentration

Sub-Watershed	Drainage Area (mi^2)	1978 Conditions CN	1978 Conditions Tc (hrs.)	100% ¼ Acre Devel. CN	100% ¼ Acre Devel. Tc (hrs.)	75% ¼ Acre 25% Open CN	75% ¼ Acre 25% Open Tc (hrs.)
1	1.59	76	5.08	79	4.96	74	4.96
2	2.72	68	3.65	76	3.48	70	3.48
3	1.24	66	3.15	72	2.91	69	2.91
4	1.17	70	14.78	74	3.01	71	3.01
5	.38	64	1.40	68	1.07	65	1.07
6	.12	70	1.80	70	.76	66	.76
7	1.40	76	5.58	76	4.23	74	4.23
8	.15	73	1.06	73	.87	70	.87
9	1.54	74	4.88	76	4.74	72	4.74
10	2.77	78	7.47	80	7.14	77	7.14
11	.58	76	1.69	76	1.30	72	1.30
12	1.07	74	2.34	76	1.88	73	1.88
13	1.37	59	1.73	67	1.57	63	1.57
14	.06	58	.31	65	.25	60	.25
15	.89	71	1.39	75	1.14	71	1.14
16	.17	53	.58	66	.39	62	.39
17	1.13	66	6.86	74	6.40	71	6.40
18	.83	56	1.21	66	.90	61	.90
19 19.32	.15	66	.60	72	.51	69	.51
20	1.30	62	2.78	71	1.90	68	1.90
21	.22	61	.66	65	.45	60	.45
22	.25	49	.61	64	.48	60	.48
23	.68	49	1.30	64	.91	60	.91
24	.18	44	.27	61	.23	57	.23
25	.33	51	1.29	65	1.16	61	1.16
26	.63	47	.63	63	.50	58	.50
27	1.01	64	1.89	70	1.85	66	1.85
28	1.15	57	1.88	67	1.42	63	1.42
29	.23	56	.76	68	.58	65	.58
30	.48	51	1.20	63	.97	59	.97
31	.10	60	.55	67	.49	63	.49
32	1.39	53	1.75	66	1.39	62	1.39
33	.32	64	1.05	68	.54	64	.54
34	.24	63	.41	71	.34	67	.34
35	.11	73	.67	78	.63	75	.63
36 [illegible]	.74	72	.74	72	.62	68	.62
37	.27	66	.65	73	.60	69	.60
	29.0						

TABLE 6

Comparison of Flows for Three Scenarios
(Flows in cfs)

		1978 Conditions			¼ Acre Development			75% ¼ Acre, 25% Open		
		2-yr.	25-yr.	100-yr.	2-yr.	25-yr.	100-yr.	2-yr.	25-yr.	100-yr.
(A) Bear Cr. u/s of trib from McCarthy Lake	7.2	100	430	640	200	640	910	130	470	700
(B) Bear Cr. d/s of Trib. from Ratigan Lake	14.7	260	860	1240	360	1110	1580	260	860	1250
(C) Bear Creek u/s of Armstrong Cr.	22.9	310	1070	1510	470	1390	1960	350	1140	1610
(D) Bear Creek u/s of Waddell Cr.	29.0	360	1250	1760	560	1640	2290	420	1370	1940

A, B, C, D - Locations indicated on Figure 2.

TABLE 7

Comparison of Flows for Each Subbasin
(Flows in cfs)

Sub-Watershed	Drainage Area (mi²)	1978 Conditions 2-yr.	1978 Conditions 25-yr.	1978 Conditions 100-yr.	¼ Acre Development 2-yr.	¼ Acre Development 25-yr.	¼ Acre Development 100-yr.	75% ¼ Acre, 25% Open 2-yr.	75% ¼ Acre, 25% Open 25-yr.	75% ¼ Acre, 25% Open 100-yr.
1	1.59	65	200	280	85	240	320	55	190	260
2	2.72	55	260	390	130	440	600	70	310	450
3	1.24	20	110	170	45	180	250	30	150	210
4	1.17	30	110	160	50	180	260	35	150	220
5	.38	5	45	70	10	70	110	7	55	90
6	.12	4	20	30	5	30	45	3	20	35
7	1.40	55	170	230	60	200	280	50	180	250
8	.15	9	40	95	10	45	60	7	35	50
9	1.54	90	180	250	65	210	280	45	170	240
10	2.77	110	310	420	130	350	470	100	310	410
11	.58	40	140	200	45	160	220	30	130	180
12	1.07	50	200	270	70	250	340	50	210	300
13	1.37	10	85	160	30	280	300	15	140	230
14	.06	1	6	13	1	15	25	1	9	16
15	.89	35	180	260	65	250	350	40	200	290
16	.17	1	6	15	4	40	65	2	30	50
17	1.13	15	70	100	35	120	160	25	100	140
18	.83	4	40	80	20	140	220	8	90	150
19	.15	4	30	50	10	50	75	6	40	60
20	1.30	15	90	150	90	220	320	30	180	270
21	.22	2	25	45	5	45	75	2	25	50
22	.25	1	5	11	4	45	75	2	30	55
23	.68	1	12	25	10	95	160	6	65	110
24	.18	*	2	4	2	30	55	1	18	35
25	.33	1	8	17	6	45	75	3	30	55
26	.63	1	9	19	8	100	180	4	55	110
27	1.01	15	100	160	35	160	240	20	120	190
28	1.15	7	55	180	25	170	260	15	120	200
29	.25	1	12	25	8	55	85	4	45	70
30	.48	1	11	25	6	60	180	4	40	70
31	.10	1	11	20	3	25	35	1	17	30
32	1.39	5	40	80	30	200	300	15	140	230
33	.32	5	45	70	10	80	120	5	55	95
34	.24	3	45	70	15	90	130	8	65	100
35	.11	8	35	50	15	50	65	10	40	55
36	.74	45	210	310	50	230	330	25	180	270
37	.27	6	55	85	20	90	130	10	70	100
	29.0									

Low Flow Analysis

Flow measurements were made at 10 locations (Figure 5) in the watershed during the study and are listed in Table 8. The drainage area shown at each site is the total drainage area including noncontributing areas. It is assumed that these areas contribute groundwater to the system which supplies the baseflow in the streams. Low flow statistics were estimated by comparing these measured flows with flows at various USGS gaging stations on other streams. The USGS gaging stations are operated continuously for a period of years. The estimated 50% and 95% monthly exceedance flows for Bear Creek at 29.6 mi^2 are listed below in cfs.

Bear Creek u/s of Waddell Creek (DA = 29.6 mi2)

	J	F	M	A	M	J	J	A	S	O	N	D
50%	24	25	42	44	29	24	21	19	20	23	26	28
95%	16	18	22	25	18	15	11	11	12	13	16	20

The 95% exceedance flow means that we would expect that much or more water in the stream 95% of the time when averaged over a long period of time. The estimated annual flow duration for Bear Creek at 29.6 mi^2 in cfs are:

10%	51
25%	39
50%	30
70%	26
75%	24
90%	20
95%	17

The estimated average annual flow is 28 cfs.

TABLE 8

Measurements Made by DNR
(Flows in cfs)

		Date	Q (cfs)	Yield (cfs/mi2)
1)	Bear Creek @ Krueter Road, DA = 5.78	6/27/91 8/28/91	3.94 3.11	.68 .54
2)	Bear Creek @ Giles Road, DA = 15.4	6/18/91	8.56	.56
3)	Bear Creek @ Ramsdell Road, DA = 16.5	6/18/91 8/28/91	10.4 7.39	.63 .45
4)	Bear Creek @ Egypt Valley Rd. DA = 22.9	6/18/91 8/28/91	18.4 12.0	.80 .52
5)	Bear Creek @ Cannonsburg Road, DA = 28.1	6/18/91	28.7	1.02
6)	Bear Creek @ Chauncey Dr., DA = 29.5	6/18/91 8/28/91	27.2 20.3	.92 .69
7)	Armstrong Creek @ Egypt Valley Rd. DA = 2.1	8/28/91	1.68	.80
8)	Pickeral Lake Outlet @ Cannonsburg Rd., DA = 1.94	6/18/91 8/28/91	1.43 .93	.74 .48
9)	McCarthy Lake Outlet @ Tiffany Road, DA = 1.33	8/28/91	.13	.10
10)	Trib. to Bear Creek @ Tiffany Road, DA = 5.36	8/28/91	.69	.13

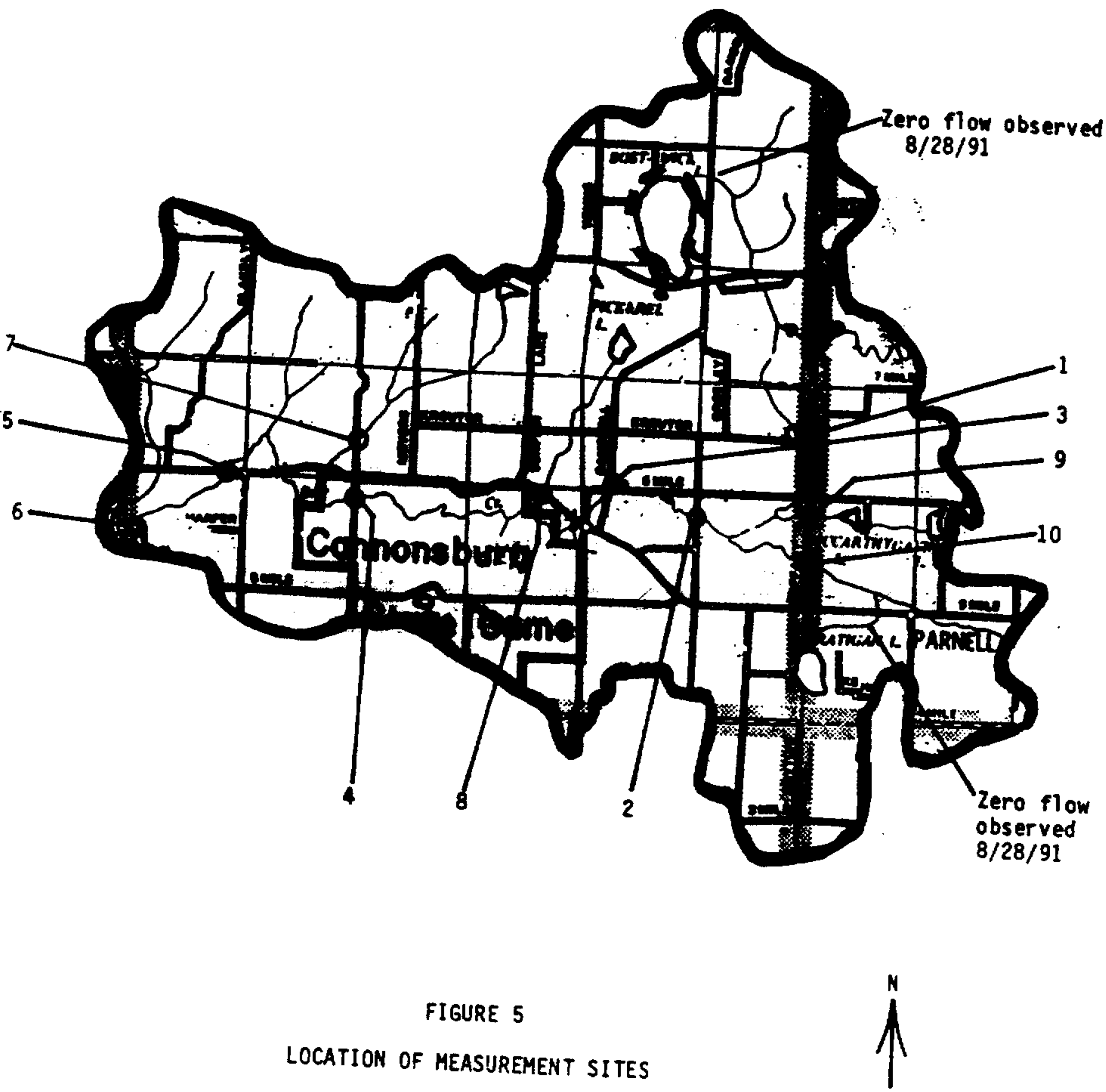


FIGURE 5

LOCATION OF MEASUREMENT SITES

Urbanization Impacts on Water Quality

Urbanization can cause substantial increases in the volume and rate of runoff from a watershed. Those increases tend to cause physical changes and degradation to the stream's water quality. Increased flows lead to channel scour and increased sedimentation. Urbanization can lead to increased stream temperature and increased pollutant levels due to more paved areas which collect oil, grease, sediment and other pollutants. These are then transported via curb and gutter and storm sewers to the stream system. Nitrogen and phosphorous levels may increase in urban area streams. This may be critical if there are lakes or ponds in the system or slow moving reaches in the stream. Concentrations of metals and pesticides may increase depending on the land use in the watershed. Bacteria levels may also increase which have caused some streams and lakes in Michigan to become unsuitable for human contact for periods of time.

Minimizing Both Water Quantity and Quality Impacts

Traditionally, urban drainage problems have been solved by getting rid of the water as quickly as possible and transporting it downstream. This was done by making the conveyance system large and efficient either with larger culverts, ditches or both. While this method may have temporarily solved the upstream problem, it only passed on and increased the problem downstream. This lead to regulations calling for detention ponds to be built which are designed to release flows at a specified release rate, usually the predevelopment rate. This can reduce the increase in downstream flows if done properly. Often the detention policy is applied to the entire watershed, even though detention in some portions of the watershed may cause an increase in flows due to the timing of the hydrographs (see Figures 6a, b, c). Detention in downstream portions of the watershed may delay the peaks from those areas so much that when added to upstream peaks the combination is higher than if there wasn't any detention in the downstream areas. This is where modeling can be beneficial. It can be used to comprehensively evaluate the entire watershed.

In addition to potentially causing downstream flooding problems, the traditional techniques do not address the problems of water quality degradation caused by the increased pollutant levels of the urban setting. The traditional techniques are usually sized for design storms ranging from 5 year to 25 year frequencies. If there are detention ponds they usually have an outlet at the bottom of the pond where everything eventually drains out with little or no settling. These detention ponds may reduce the peak outflows to pre-existing rates which will help in preventing increased channel erosion due to increased flows and velocities. They do not, however, address the concerns of additional pollutants, including sediment being delivered to the stream due to urbanization. Most of these pollutants are picked up and transported to the stream during the small rain events which produce runoff. From a water quality standpoint, these small rainfall events, up to 2 year rainfall, need to be designed for using infiltration, extended detention or wet ponds where settling can occur over a 24-48 hour period. This is in addition to maintaining predevelopment flow rates for the higher frequency storms.

The amount of runoff volume which is designed for using infiltration, extended detention or wet ponds varies across the county. Some of the criteria are listed below:

- runoff volume equal to ½ inch per acre of impervious area
- runoff volume equal to ½ inch per acre of contributing area
- runoff volume equal to amount generated by one inch storm
- runoff volume equal to the amount generated by a 1 year or 2 year 24 hour storm

In Michigan it usually rains ½ inch or more about 18-24 times a year. A rainfall of 1 inch or more will occur approximately 7-8 times a year. A 1 year 24 hour storm ranges from 1.8 inches in northern Michigan to 2.4 inches in southern Michigan, while the 2 year 24 hour storm ranges from 2 inches to 2.7 inches.

When feasible, infiltration should be the preferred method for water quality design. The infiltration rates of the underlying soils must be .52 inches/hour or greater. This rate is normally found with A and B type soils (Table 1). Typical design configuration for extended dry detention basins and wet ponds are shown in Figures 7 and 8. A 1991 Stormwater Management Guidebook by the Michigan Department of Natural Resources describes various design considerations for extended wet and dry detention, infiltration basins, grassed swales and oil and grease separators.

Figure 9 by Schueler lists various BMP's with drainage areas for which they are estimated to be effective for. Figure 10 also by Schueler lists various BMP's and the types of soils for which they may be effective.

Some other types of BMP's which can help in the urban setting are:

1) Buffer or greenbelt areas along all streams and wetlands. No ground may be disturbed in this area. Buffer widths requirements vary across the country from 25 feet to 200 feet.

2) Sediment sumps in storm sewers - should be cleaned out when they are 60% full. Cleaned at least twice a year, before first snowfall and after spring snowmelt.

3) Maintaining as much vegetation and green area as possible.

4) Using grassed swales instead of curb and gutter.

5) Disconnecting downspouts from the storm sewers.

Temperature Considerations

High quality streams are usually very temperature dependent. Slight increases in water temperature may seriously decrease or eliminate sensitive fish species such as trout. A study by Galli (1990) done in Maryland found that the temperature of an urban stream increased linearly .14° F per 1% increase in imperviousness. Thus, a 60% increase in imperviousness within a watershed would raise the stream temperature 8.4° F. The study also noted that vegetation and canopy cover along streams helps to control the rise in water temperature during the summer. Removal of this vegetation and canopy could cause a rise in temperature of 11-20° F in the summer with associated cooler winter temperatures. On smaller streams, water temperatures may increase 1.5° F per 100 feet when flowing through unshaded areas. The study indicates that trout and other cold water biota may not be able to survive when the watershed imperviousness exceeds 12-15%. If temperature control is a critical element with a stream, then land use controls, stream buffer requirements and other BMP's which limit temperature increases are important. Galli found that infiltration is the best alternative when temperature is critical. Shading of the pond and the inflow and outflow channels of the detention/retention ponds was also found to be important.

Construction Site Erosion

Soil erosion from new construction sites, including roads, appears to be a major concern in many areas of the state. Critical wetlands and stream reaches have been destroyed due to poor soil erosion practices. Adequate soil erosion control, enforcement and follow-up are needed in watersheds where development pressure is occurring.

A 1990 study by Scheuler and Lugbill on "Performance of Current Sediment Control Measures at Maryland Construction Sites" had the following findings and recommendations.

- Vegetative stabilization and other erosion control measures are the first and most important aspect in preventing off-site movement of sediment. These measures must be established quickly, maintained and inspected.

- The performance of the sedimentation erosion controls is greatest in the early part of construction when the amount of imperviousness is still minimal.

- When possible do the construction in a staged manner. Avoid clear cutting and grading the entire site at once. Work on one area and let it stabilize before moving on.

- Restrict development in environmentally sensitive areas and possibly use cluster development which minimizes the disturbed area.

- The study recommends a sediment basin volume of 3600 cubic feet/acre with a combination of wet and dry storage. The wet storage helps against resuspension of sediments.

- 60% of the sediment was removed in 6 hours, 90% was removed after 48 hours. Settling velocities are listed in Table 9 (Ref. 7). Detention times of at least 6 hours should be provided.

TABLE 9

Settling/Particle-Size Relationships

PARTICLE SIZE CLASSIFICATION	PARTICLE DIAMETER (microns)	SETTLING VELOCITY (ft/hr)
SAND		
Very Coarse	1000-2000	128
Coarse	500-1000	65
Medium	250-500	34
Fine	125-250	16
Very Fine	62-125	6
SILT		
Coarse	31-62	1.4
Medium	16-31	.4
Fine	8-16	.1***
Very Fine	4-8	.02***
CLAY	>4	.055***

(***Discrete particles in still water. Actual velocities may be 1.5 to 6 times less rapid.)

At a 1991 Stormwater Conference at Grand Valley State University, some of the following ideas were presented by Doug Sporte of the City of Kentwood on enforcing soil erosion (Ref. 10).

- Don't accept site plans unless they contain adequate soil erosion and stormwater controls.

- Require a performance bond for completion of soil erosion controls and site stabilization. Contact bond company if work is not completed.

- Make sure the contractor is working with the most recent set of plans.

- Issue a stop work order if violation is bad enough.

- Require a greenbelt buffer along all streams, drains, pond and wetlands.

- Limit floodplain activity.

- Stormwater and soil erosion control should be the first things built. Any permanent structure should be able to handle the entire site even if only a portion is being constructed now.

- Deny occupancy if final job is not stabilized and problems are not corrected.

FIGURES 6a, b, c

INCREASED FLOOD PEAK DUE TO DETENTION

REF. 3 and 5

Figure 6b

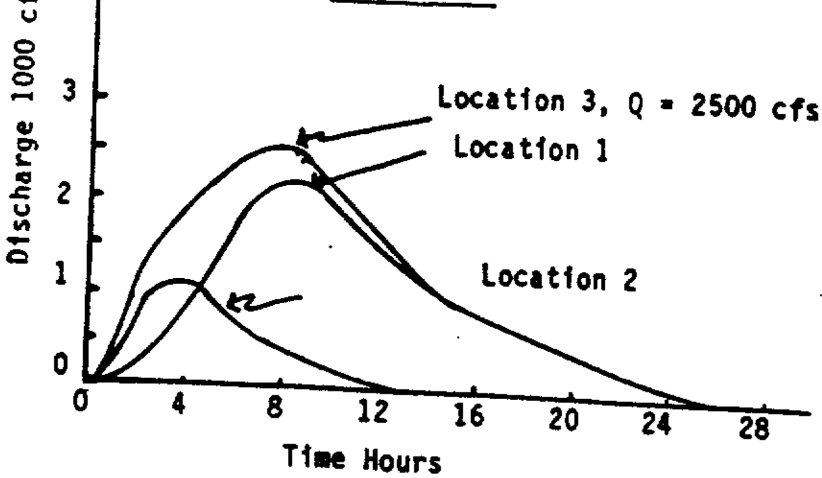
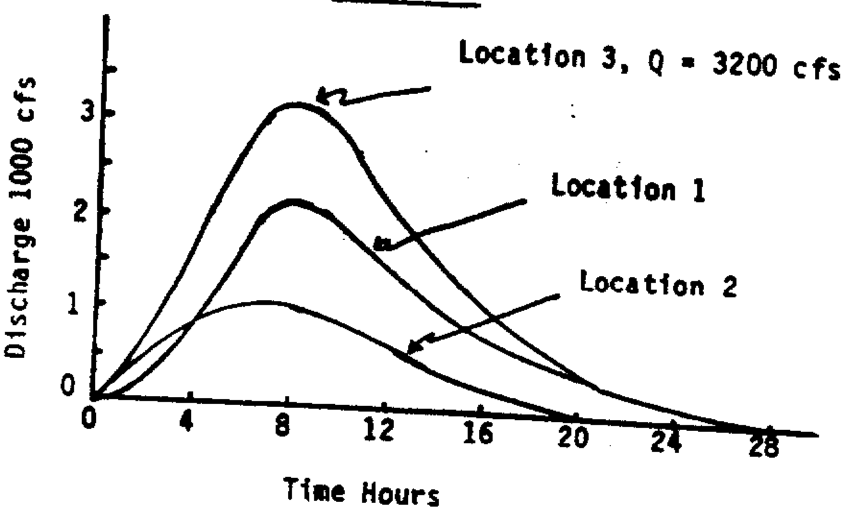


Figure 6c



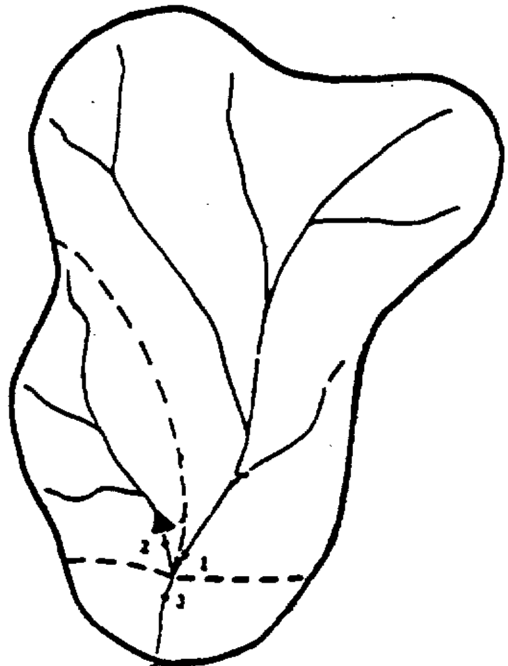


Figure 6a

Explanation

Figure 6b shows three hydrographs for undeveloped conditions at locations 1, 2 and 3 in Figure 6a. The hydrograph at location 3 with a peak discharge of 2500 cfs represents the combined flows of hydrographs 1 and 2. Figure 6c shows three hydrographs assuming area 2 was developed and had a detention pond constructed. Even though the peak from area 2 is the same, it's timing is delayed enough so that when it is added to hydrograph #1, the resultant peak at location #3 increases to 3200 cfs.

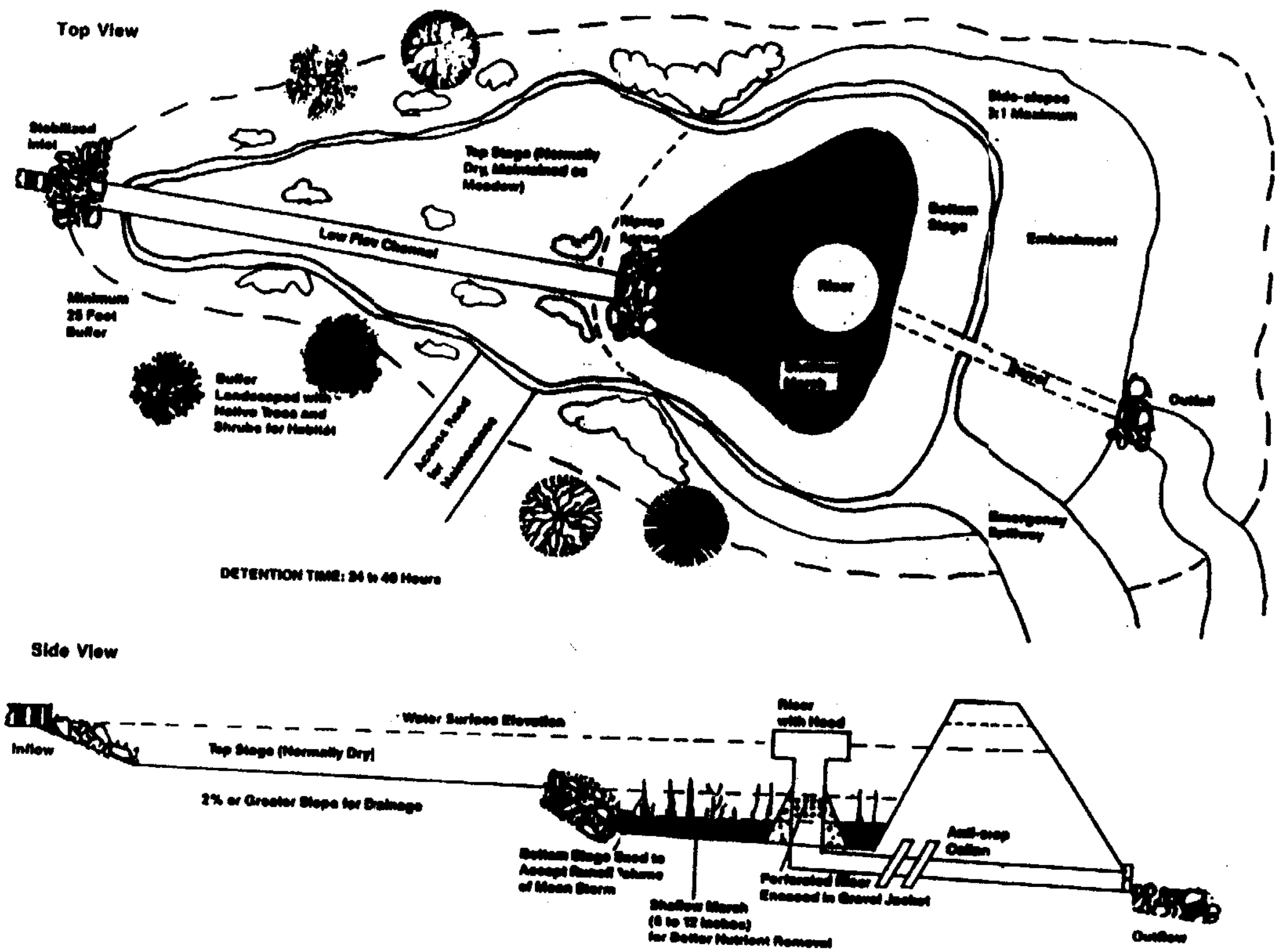


Figure 7 - **Extended Detention Pond**

Source - Schueler, 1987, Reference 6

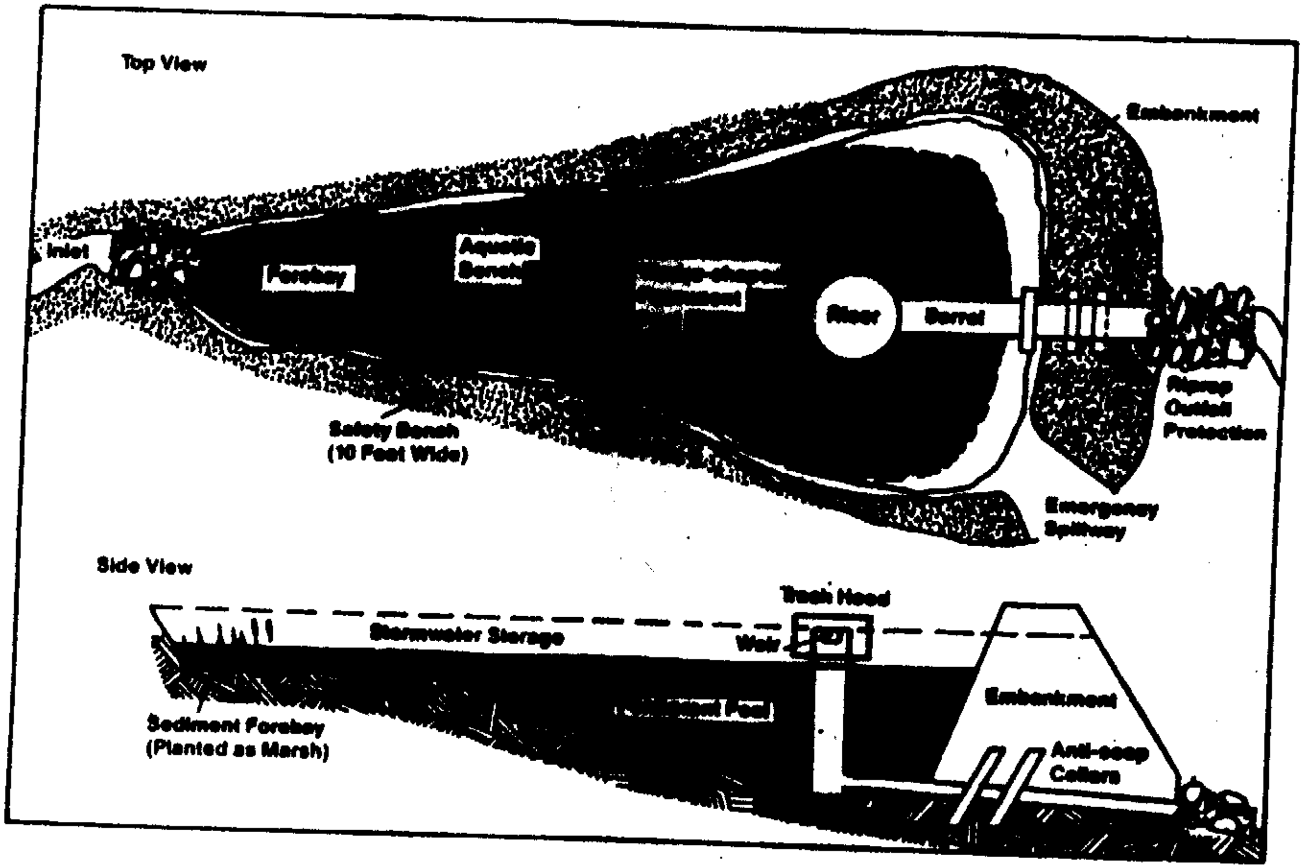


Figure 8 - Wet Detention Pond

Source: Schueler, 1987, Reference 6

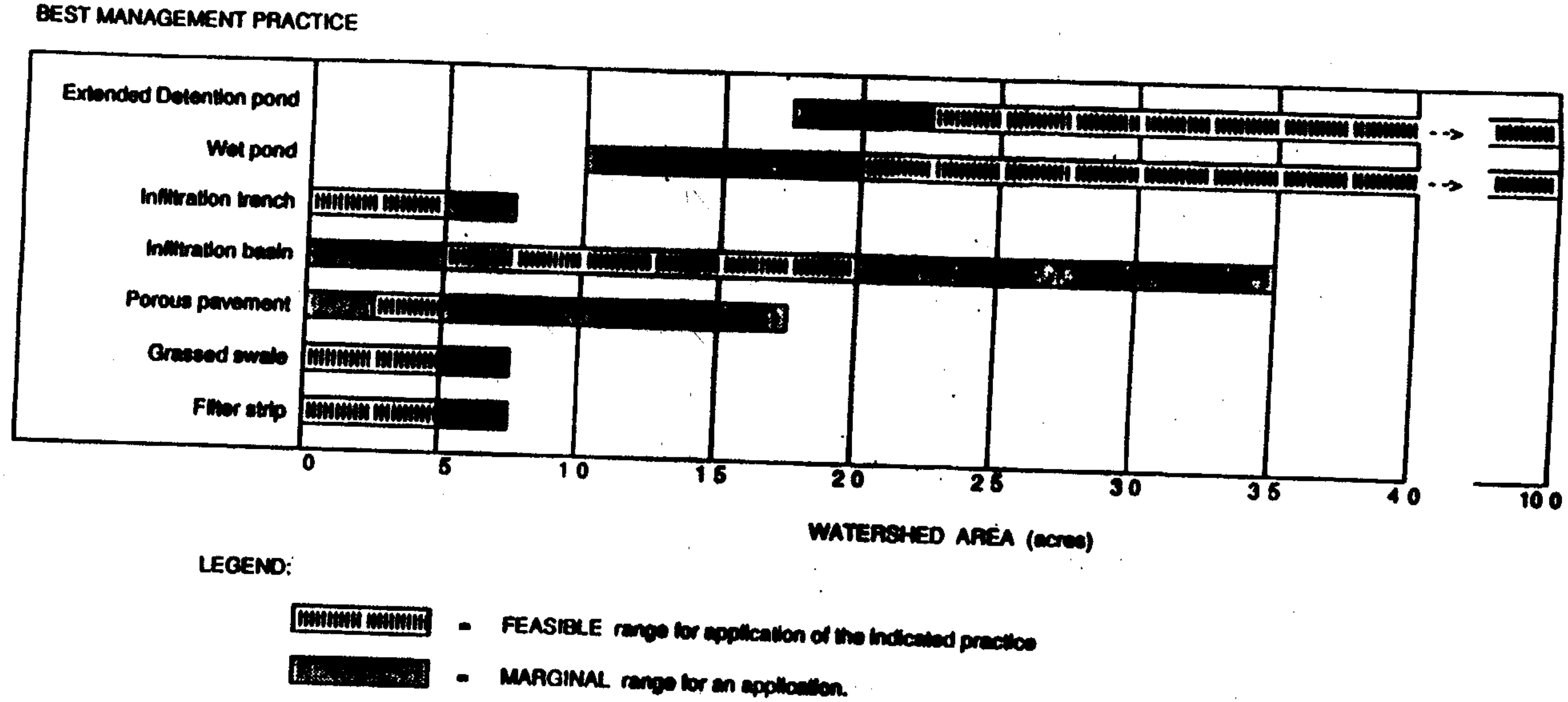


FIGURE 9 FEASIBLE BMP TYPES FOR DIFFERENT SIZES OF WATERSHED

(Ref. 6 & 14)

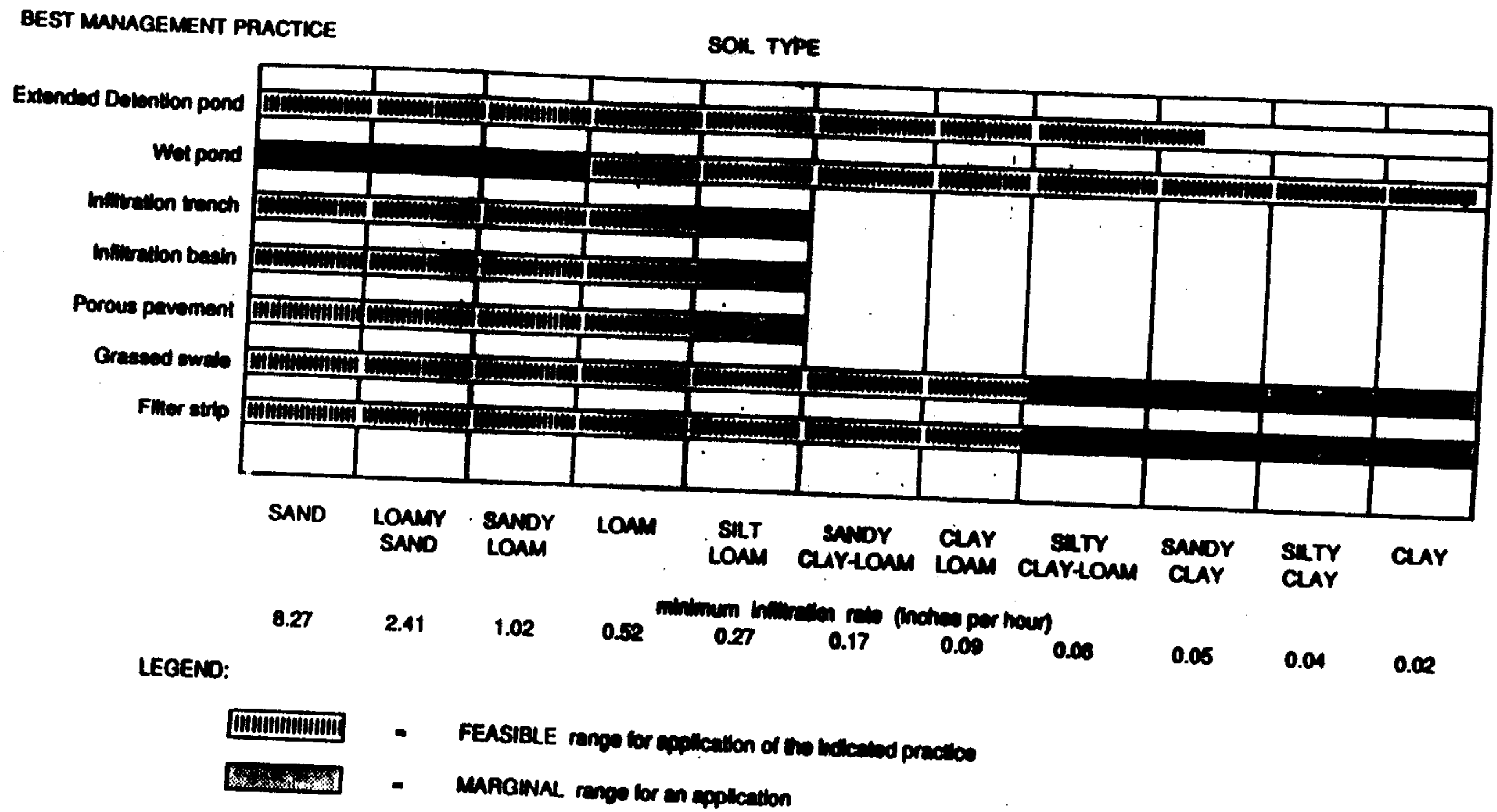


FIGURE 10 RESTRICTIONS FOR APPLICATION OF BMPs BASED ON SOIL PERMEABILITY
(Ref. 6 & 14)

APPENDIX A

Table 10

MIRIS

CURRENT LAND COVER/USE LEGEND

1 URBAN
- 11 RESIDENTIAL
  - 111 MULTI-FAMILY, HIGH RISE
  - 112 MULTI-FAMILY, LOW RISE
  - 113 SINGLE FAMILY, DUPLEX
  - 115 MOBILE HOME PARK
- 12 COMMERCIAL, SERVICES, INSTITUTIONAL
  - 121 PRIMARY/CENTRAL BUSINESS DISTRICT
  - 122 SHOPPING CENTER/MALL
  - 124 SECONDARY BUSINESS/STRIP COMMERCIAL
  - 126 INSTITUTIONAL
- 13 INDUSTRIAL
  - 138 INDUSTRIAL PARK
- 14 TRANSPORTATION, COMMUNICATIONS, UTILITIES
  - 141 AIR TRANSPORTATION
  - 142 RAIL TRANSPORTATION
  - 143 WATER TRANSPORTATION
  - 144 ROAD TRANSPORTATION
  - 145 COMMUNICATIONS
  - 146 UTILITIES
- 17 EXTRACTIVE
  - 171 OPEN PIT
  - 172 UNDERGROUND
  - 173 WELLS
- 19 OPEN LAND, OTHER
  - 193 OUTDOOR RECREATION
  - 194 CEMETERIES

2 AGRICULTURE
- 21 CROPLAND
- 22 ORCHARDS, BUSH FRUIT, VINEYARDS, ORNAMENTAL HORTICULTURE
- 23 CONFINED FEEDING
- 24 PERMANENT PASTURE
- 29 OTHER

3 NONFORESTED
- 31 HERBACEOUS
- 32 SHRUB

4 FORESTED
- 41 DECIDUOUS
  - 411 NORTHERN HARDWOOD
  - 412 CENTRAL HARDWOOD
  - 413 ASPEN/WHITE BIRCH ASSOCIATION
  - 414 LOWLAND HARDWOOD
- 42 CONIFEROUS
  - 421 PINE
  - 422 OTHER UPLAND CONIFER
  - 423 LOWLAND CONIFER
  - 429 CHRISTMAS TREE PLANTATION

5 WATER
- 51 STREAM
- 52 LAKE
- 53 RESERVOIR
- 54 GREAT LAKES

6 WETLANDS
- 61 FORESTED
  - 611 WOODED
  - 612 SHRUB, SCRUB
- 62 NONFORESTED
  - 621 AQUATIC BED
  - 622 EMERGENT
  - 623 FLATS

7 BARREN
- 72 BEACH, RIVERBANK
- 73 SAND DUNE
- 74 EXPOSED ROCK

APPENDIX B
TABLE 11

SCS 24 HOUR TYPE I RAINFALL 30 MINUTE INTERVALS

.000	.008	.017	.026	.035	.045	.055	.065	.076	.087
.099	.112	.125	.140	.156	.174	.194	.219	.254	.30
.515	.583	.624	.654	.682	.705	.727	.748	.767	.784
.800	.816	.830	.844	.857	.870	.882	.893	.905	.916
.926	.936	.947	.955	.965	.974	.983	.992	1.000	

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